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## Prevention of Loss of Consciousness with Positive Pressure Breathing and Supinating Seat

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Maintaining vision and consciousness at high sustained  $+G_z$  requires a total body effort for most people, and is very fatiguing. Currently, the only pieces of operational G-protective equipment are the anti-G suit and anti-G valve which provide relaxed G-tolerance protection to about 5.5 G. Protection above 5.5 G requires the anti-G straining maneuver (AGSM). Assisted positive pressure breathing (APPB) has been shown to augment sustained  $+G_z$  tolerance and reduce the amount of straining necessary to maintain a specific  $+G_z$  level. Moreover the supinating seat has been shown to double relaxed G tolerance at a back angle of 75° from the vertical when compared to relaxed tolerance at a 13° or 30° position. Problems of cockpit engineering, escape, head-rest angle, restricted rear visibility, and pilot acceptance of a high angle supinated seat may preclude the use of a seat with sufficient back angle to provide "no strain" G protection. Thus, the addition of APPB to a limited protective seat may provide adequate and acceptable G tolerance.

**P**REVENTION OF LOSS of consciousness during  $+G_z$  (G-LOC) is dependent upon the maintenance of adequate arterial blood pressure at head level. The anti-G suit, the anti-G straining maneuver (AGSM), and the forward crouch are the only current operational protective means to maintain adequate head level blood pressure and consciousness during LOC-threatening  $+G_z$ . A well-fitted anti-G suit provides a fairly standard, reproducible increase in  $+G_z$  tolerance. The protective benefits of the AGSM are, however, only as great as the effectiveness of its performance; i.e., a poor AGSM provides little or no protection, whereas a very efficient and effective AGSM can provide G protection to 9  $+G_z$ , and probably higher. The upper limit of  $+G_z$

protection with the AGSM has never been determined. The AGSM is a total body effort, and has a high fatigue factor. Thus, fatigue becomes an important potential causative G-LOC factor during subsequent  $+G_z$  encounters.

In our search for methods to protect the pilot and reduce the effort of maintaining consciousness during high  $+G_z$  maneuvering, the supinating seat and positive pressure breathing (PPB) are two techniques that have been investigated and shown to effectively reduce fatigue and increase G tolerance. Both of these techniques have been proposed at one time or another for operational G protection. These protective techniques will be discussed separately, and then together as a possible combined protection technique.

In 1966, Ernsting reported an increase in blood pressure during application of PPB (8). Moreover, the increase in blood pressure was directly related to the amount of body surface area over which counterpressure was applied, and reached 100-125% of applied PPB with trunk and limb counterpressure. Shubrooks later utilized the PPB technique in an investigation of G-tolerance enhancement. He demonstrated an improvement in  $+G_z$  tolerance over and above that provided by the anti-G suit, using continuous, unassisted (no chest counterpressure) PPB (15). Protection was similar to that of the M-1 straining maneuver, but less fatiguing. Other studies using unassisted PPB have confirmed these findings (2,6,10-13).

Although unassisted PPB has been shown to have limited value as protection during a simulated aerial combat maneuver (4.5-7.0  $+G_z$ ) on the centrifuge (14), the Royal Air Force (United Kingdom) has successfully flight tested unassisted PPB to 35 mm Hg at 6  $+G_z$  (1). The pilots were enthusiastic about the PPB and considered it more effective and less fatiguing than the AGSM. However, the addition of chest counterpressure at the same pressure as at the

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facemask (assisted PPB = APPB) has proven to be very beneficial for fatigue reduction during simulated aerial combat maneuvering (SACM), and has allowed higher levels of PPB. Shaffstall and Burton (14) observed a 40% increase in time at  $+G_z$  during a continuous 4.5 to 7  $+G_z$  SACM with APPB of 35 mm Hg. Also, Burns and Balldin (4), using APPB of 50 and 70 mm Hg, demonstrated a 115% and an 88% respective increase in tolerance time during a continuous 5 to 9  $+G_z$  SACM compared to the same 5 to 9  $+G_z$  SACM without APPB. The APPB was easily tolerated by the subjects and, in fact, was anxiously anticipated at 9  $+G_z$ . Not only does APPB increase blood pressure (8) but it also facilitates inspiration, which, according to the subjects, may be its greatest benefit at high  $+G_z$ .

These encouraging results have led to the proposal that APPB may be useful in protecting high performance fighter pilots against the current, highly visible, operational problem of G-LOC. Several systems have been developed to provide APPB during  $+G_z$ . These systems have been successfully flight-tested with potential for retro-fit into F-15 and F-16 aircraft. However, current data indicate that APPB has little value for G-LOC protection during relaxed rapid onset (6  $G \cdot s^{-1}$ )  $+G_z$  exposure.

Table IA illustrates the response of five relaxed subjects to rapid onset (6  $G \cdot s^{-1}$ )  $+G_z$ , both with and without APPB. The anti-G suit was used during both conditions. APPB was provided at the rate of 12 mm Hg  $\cdot G^{-1}$ , starting at 4.0  $+G_z$ . Note that APPB provided an insignificant 0.4  $+G_z$  increase in tolerance. However, at 5.5  $+G_z$ , APPB would be only 18 mm Hg—hardly enough APPB to effect a significant increase in G tolerance. On the other hand, Table IB illustrates the response of the same five relaxed subjects to a step increase in APPB to 60 mm Hg, beginning at 1.2  $+G_z$ . A 60 mm Hg increase in arterial blood pressure, resulting from the application of 60 mm Hg APPB, theoretically should provide an improvement in  $+G_z$  tolerance of greater than 2.0 G (assuming a 25 mm Hg reduction of eye-level blood pressure per  $+G_z$ ). From Table IB note that the increase in  $+G_z$  relaxed tolerance from the 60 mm Hg step increase in APPB, although significant, averaged only 0.7 G. In a relaxed subject, the increase in blood pressure resulting from APPB is attenuated by a concomitant reduction in venous return due to the rise in intrathoracic pressure. Ernsting's data (8) illustrate about a 7-s delay from the time of peak APPB level to the time of peak blood pressure response. Thus, a delay of this magnitude is too great to be beneficial, and possibly explains the less than anticipated G tolerances observed during these 6  $G \cdot s^{-1}$   $+G_z$  exposures, where visual symptoms begin to appear within 5 s of peak  $+G_z$  level. Moreover, part of the increase in G tolerance during APPB,

with both the standard APPB schedule and with the 60 mm Hg step increase in APPB, could possibly be attributed to uncontrolled straining against the APPB and anti-G suit, and might not be due completely to the APPB blood pressure response per se. Even though the subjects were trained and instructed to relax during the  $+G_z$  exposures, maintenance of relaxation under conditions of APPB and anti-G suit inflation is very difficult and takes considerable self control.

In contrast, the fatigue reduction benefits of APPB during the AGSM at high levels of  $+G_z$  may play a significant role in G-LOC protection. By being less fatigued from previous  $+G_z$  exposure with APPB support, a pilot would be more able to tolerate subsequent  $+G_z$  exposures.

Unquestionably the supinating seat provides significant G protection and can provide G-LOC protection (3,5,7,9–11,16). The greater the back angle from the vertical, the less straining is required to maintain a specific G level. At some back angle no straining will be required. At a back angle of 75° from the vertical a mean relaxed tolerance of 8.0 G has been demonstrated (3). Unfortunately, the "no strain" back angle is generally greater than is practical or acceptable for inclusion in current or near future cockpits. Moreover, head rest angle is a significant negative factor in supinating seat G tolerance (5). A penalty is paid, resulting in loss of G tolerance, when the eye-to-heart hydrostatic column is increased at greater head rest angles, as the head is raised into the  $+G_z$  vector for better cockpit visibility. Problems of cockpit engineering, escape, head-rest angle, restricted rear visibility, and pilot acceptance of a high angle supinated seat may preclude the use of a seat with sufficient back angle to provide "no strain" G protection. Under those circumstances, the addition of APPB to a limited protective seat may provide adequate and acceptable G tolerance (10,11). In addition, at increased back angles,  $+G_x$  becomes a significant factor in chest discomfort or pain and in the ability to breathe, as previously pointed out (10,11). The application of APPB could alleviate this problem by counteracting the  $+G_x$  load on the anterior chest wall and by reducing the effort of inspiration. We are currently investigating the combined benefits of the supinating seat and APPB with the hope of finding a combination that will provide an additional 1.5–2.5 G of protection, compared to the upright seat, thus overcoming the negative effect of maintaining the head in the upright position at increased back angles.

#### ACKNOWLEDGMENTS

The voluntary informed consent of the subjects used in this study was obtained in accordance with AFR 169-3. All subjects have passed medical examinations required for centrifuge exposure.

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TABLE I. RELAXED  $+G_z$  TOLERANCE DURING APPB.

	A Standard APPB Schedule		B 60 mm Hg Step Increase In APPB	
	Without APPB	With APPB	Without APPB	With APPB
$\bar{x}$	5.1	5.5	5.2	5.9*
S.E.	$\pm 0.1$	$\pm 0.2$	$\pm 0.1$	$\pm 0.2$

Standard APPB schedule = 12 mm Hg  $\cdot G^{-1}$  after 4.0  $+G_z$  to a maximum of 60 mm Hg at 9  $+G_z$ . Step increase in APPB occurred around 1.2  $+G_z$ . The G-suit was used during all exposures. n = 5; \* = p < 0.025 compared to "Without APPB."

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